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BENTHIC HABITATS IN SHIMMO CREEK, NANTUCKET, MA

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Cover Image: Upper Left, *Tanaid* taken from Shimmo Creek. Upper Right, *Hediste diversicolor* taken from Shimmo Creek. Lower Left, Sidescan Mosaic of study area. Lower Right, picture of survey platform, R/V Portnoy.

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Executive Summary

Oyster reefs, particularly those created by the Eastern Oyster (*Crassostrea virginica*), are important biogenic structures along the Western Atlantic coast. Oyster reefs are valued not just for their resource as a fishery, but as important habitat providing a myriad of ecosystem services including water filtration and concentration of pseudofeces (undigested material that is excreted), providing habitat for epibenthic invertebrates, nutrient sequestration, augmented fish production, and stabilization of adjacent habitats and shoreline (Grabowski and Peterson 2007). More recently, creating oyster reefs in areas that historically have not held oyster habitat, has been seen as a possible way to improve the quality of surrounding habitat and to buffer chronic anthropogenic stressors, such as nutrient loading resulting in poor water quality. One such project took place in Shimmo Creek, Nantucket in the summer of 2017 and 2018.

The mouth of Shimmo Creek is a small embayment along the southern shore of Nantucket Harbor. Poor water quality characterizes this area and historical anecdotal evidence of oysters persisted. The town of Nantucket recently created oyster habitat and laid recycled bivalve shell (primarily oyster, scallop, and quahog) across approximately 1 acre. As long-term monitoring is needed to understand the ecological function and to inform future efforts, the Center for Coastal Studies Seafloor Mapping Program conducted a benthic habitat survey in August of 2018.

Vessel-based acoustic data, bottom grab samples, and video surveys produced several data products useful for characterizing the physical and biological elements of benthic habitats. The final data products and our interpretations were made using the Coastal and Marine Ecological Classification Standard (CMECS) as a guiding element. Shimmo Creek was mapped on August 9th 2018, had a mean depth of 1.22 m across 1.30 ha of bathymetry and 2.65 ha of sidescan backscatter imagery. On August 30th 2018, 6 stations within Shimmo Creek were sampled in triplicate, resulting in a total of 18 sieved and preserved biological samples. Sampling was stratified across: 2 'On-Reef'; 2 'Off-Reef'; and 2 'Reference' at the mouth of Shimmo Creek. In addition, sediment samples, water quality data, and video data were collected at each station.

Analysis of Shimmo Creek samples documented 56 species and 17,900 individuals. Statistical analysis indicated two Biotic Communities as the optimal number. Sediment variables explained 87.8% of species distribution, indicating sediment type as the key characteristic in determining diversity and abundance in Shimmo Creek. Sediment characteristics were a bigger driver of community differences at this point as the habitat matures. Two dominate species were identified (*Gemma gemma, Hydrobia sp.*) in the cluster analysis, which were also the most abundant species, suggesting that they play an important role in the overall composition of benthic communities in Shimmo Creek.

This oyster restoration project took place in an area of Shimmo Creek that has several inherent challenges for the establishment of self-sustaining, long-term oyster habitat, primarily heavy siltation. The lack of live oysters on any of the shells collected in the benthic invertebrate grabs and on 3 of the 4 quadrate samples, indicates that after reef construction in 2018, no successful settlement of oyster larvae has occurred. If there is abundant oyster larvae in the area,

oyster larvae likely suffer high mortality due to siltation and detritus. Benthic invertebrate communities held higher diversity and higher abundance at ‘On-Reef’ stations (28 species, 892 individuals) compared to the ‘Off-Reef’ stations (12 species, 55 individuals) but contained less species and lower abundance when compared to that of the ‘Reference’ station (33 species, 16408 individuals) at the mouth of the embayment, only 10s of meters away.

As the created habitat matures into a living oyster reef it is expected that species diversity and abundance will be significantly higher than are currently present. Based on the findings of this survey there are several recommendations. Due to this silt and detritus present more cultch material is recommended to be planted in mound form, at least 0.5 m above the surrounding substrate. This will aid in the creation of micro-eddies caused by tidal currents, which could aid in transporting the sediment off the reef. The addition of spat on shell or transplanting mature oysters onto the reef will benefit the habitat by attracting oyster larvae and moving the silt off the reef via water filtration by oysters. This will also create a nearby source of larvae to create future generations of oysters. This study establishes a baseline to compare future monitoring efforts too as this reef ages. The combination of acoustic and invertebrate survey described here, interpreted within the Coastal and Marine Ecological Classification Standard will allow for long-term monitoring of these sites in a science-based manner that is rigorous, repeatable and defensible.

Introduction

Oyster reefs, particularly those created by the Eastern Oyster (*Crassostrea virginica*), are an important biogenic structures' along the Western Atlantic coast. Oyster reefs are valued not just for their resource as a fishery, but as habitat providing a myriad of ecosystem services including water filtration and concentration of pseudofeces, provision of habitat for epibenthic invertebrates, nutrient sequestration, augmented fish production, stabilization of adjacent habitats and shoreline (Grabowski and Peterson 2007). The global loss of wild oyster reefs is estimated at 85%, resulting from anthropogenic changes in water quality, habitat alteration, and over-fishing (Beck et al. 2007). The restoration and creation of oyster reefs throughout the coastal United States has become an important tool in restoring ecosystem functioning to nearshore habitats. More recently the creation of oyster reefs in areas that historically have not held oyster habitat, has been seen as a way to improve the quality of surrounding habitat and consequently, to buffer chronic anthropogenic stressors such as nutrient loading resulting in poor water quality.

The mouth of Shimmo Creek is a small embayment along the eastern shore of Nantucket Harbor (Figure 1). Poor water quality characterizes this area, thus the town of Nantucket recently created oyster habitat in order to take advantage of the beneficial ecosystem services oyster reefs can provide. In the summer of 2017 and 2018, the Town laid recycled bivalve shell (primarily oyster, scallop, and quahog) across approximately 1 acre in eight 10 – 14 ft rows. In order to document how the newly created habitat is functioning, biological and physical metrics are measured and monitored over time. One important, measurable and reproducible ecosystem functions is the quantification of diversity and abundance of benthic invertebrates.

In order to create a baseline inventory to assess current status and to measure future change, the Center for Coastal Studies (CCS) conducted a benthic habitat survey of recently created oyster reefs in Shimmo Creek, Nantucket Harbor. In August of 2018 vessel-based acoustic surveys yielded co-located, high resolution swath bathymetry and sidescan sonar imagery. Those data were coupled with bottom grab samples collected to characterize the benthic invertebrate community. Together, these data provide the basis for developing an assessment of the surficial benthic habitats as well as the macroinvertebrate communities that are present in and around the oyster beds. This information will also serve as a baseline dataset from which to conduct repeat surveys to assess the health of these areas through time.

Benthic Habitat Maps

In August of 2018 the CCS conducted surveys in Shimmo Creek (Figure 1) to characterize submerged marine habitats. We collected vessel-based acoustic data and bottom grab samples and produced several data products useful for characterizing the physical and biological elements of benthic habitats. We chose statistical tools that would produce results that are useful to create a baseline based on the success of the oyster restoration measured over time. By linking the physical and biological information within a predictive framework, the results reported here allow future inference of species composition based on physical data alone. The final data products and our interpretation were made using the Coastal and Marine Ecological Classification Standard (CMECS) as a guiding element. CMECS is mandated for all federally-funded benthic habitat maps and is quickly becoming the standard for this type of mapping. This will prove invaluable going forward for the town as this mapping method will ensure that future studies will compare 'apples to apples' by providing town scientists and outside investigators with a well-documented, rigorous, and repeatable methods for mapping and studying this system.

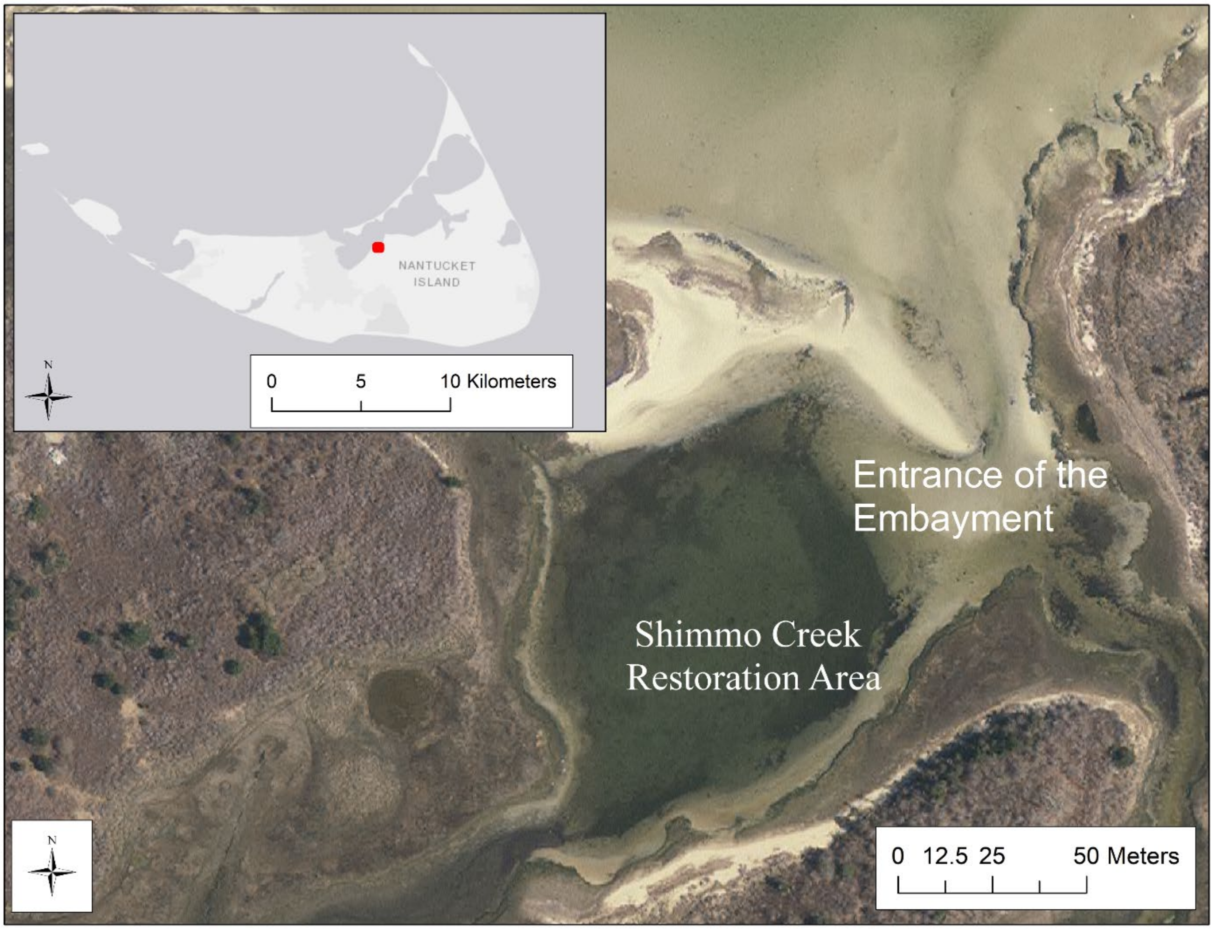

Figure 1. Locus map of the mouth of Shimmo Creek containing the area in which an oyster habitat project took place in 2017.

The purpose of this work was to integrate the physical and biological characteristics of benthic habitats from data obtained by CCS into a series of maps that describe the CMECS 'Geoform', 'Substrate', and 'Biotic' Components. CMECS itself is 'data agnostic' (FGDC 2012), meaning that as a classification scheme, it does not prescribe a particular method, set of methods, or analysis techniques. CCS collected vessel-based acoustic data and bottom grab samples, and produced several data products useful for characterizing the physical and biological elements of benthic habitats. This was done to determine ecologically-meaningful physical-biological linkages, if any, and develop full-coverage habitat maps in a rapid and reproducible manner.

Methods

Vessel-Based acoustic surveys

Hydrographic surveys were conducted onboard the Research Vessel (R/V) Portnoy (Figure 2), a 14 ft (4.3 m) custom-built pontoon designed for surveying in low-energy, estuarine environments in which a narrow turn radius and ultra-shallow draft (< 1m) are required (Borrelli et al., in press). The sonar is mounted at the end of a retractable pole positioned between the two pontoons at the bow, and is lowered to 0.3 below the waterline. This configuration significantly reduces noise from the hull and engine, improving data quality. Ancillary positioning and motion sensors are attached to fixed mounts located on the pole and are vertically aligned with the sonar. A removable crossbar is attached near the top of the pole and the receivers used for heading are mounted at the port and starboard ends of the crossbar precisely 2 meters apart. The GPS receiver is mounted at the top of the pole directly above the sonar head.

Figure 2. The pontoon boat R/V Portnoy used for acoustic surveys.

High resolution swath bathymetry and sidescan data were obtained using the Edgetech 6205 dual-frequency, phase-measuring sidescan sonar. Its operating frequencies are 550 and 1600 kHz for sidescan backscatter imagery and 550 kHz for bathymetry. The sidescan sonar range resolution is 1 cm, and the horizontal beamwidth is 0.5 degrees at 550 kHz. The corresponding quantities at 1600 kHz are 0.6 cm and 0.2 deg. The horizontal and vertical resolution of the bathymetric data are both 1 cm. The respective bandwidths at 550 and 1600 kHz are 67 and 145 kHz (Edgetech, 2014). The effective bathymetric swath width is 6-8 times the height of the sonar over the bottom, therefore, in 1m of water the effective bathymetric swath width is 6-8 m. A Teledyne TSS DMS-05 Motion Reference Unit mounted on the sonar collects data on heave, pitch, and roll, measuring heave to 5 cm and roll and pitch to 0.05° (Teledyne TSS, 2006). A HemisphereGPS® V110 vector sensor is used to measure heading. As mentioned above, two differential GPS receivers spaced 2 m apart yield heading accuracies of <0.10° RMS (HemisphereGPS, 2009). A Trimble® R10 GNSS receiver utilizing Real-Time-Kinematic GPS (RTK-GPS) is used for positioning and tide correction for vessel-based surveys. Horizontal location data are collected in WGS-84 and elevation data are collected in the vertical datum NAVD-88 Meters.

Edgetech's Discover Bathymetric® was used to monitor all incoming data streams and control settings for onboard acoustic instruments to optimize data quality for at-sea conditions. Survey planning was performed using Hypack Survey® for line planning, coverage mapping and helmsman navigation. Both, Discover Bathymetric® and Hypack's Hysweep® were used to collect data with the final raw output in .JSF and .HSX file formats respectively. The JSF files were imported into SonarWiz® where a combination of automated and manual data processing was undertaken including bottom tracking, slant range correction, offset entry and gain setting adjustments. After appropriate processing of each data file mosaics were generated then exported as Geotiffs.

Post-processing of bathymetric data was performed using CARIS HIPS®. Raw HSX files were converted to CARIS HDCS format using vessel configuration files developed from vessel offsets and device information. Sound velocity corrections were applied using measurements collected in-situ by an internal sound velocimeter located in the sonar housing and water column prs obtained from casts performed for each survey using a Sontek Castaway® CTD. Select filters were then applied to the data in order to remove noise and spurious soundings. Surfaces are created from the processed sounding data (x, y, z) and were exported to multiple raster formats including Geotiffs, Digital Elevation Models (DEMs), and Bathymetric Attribute Grids (BAGs).

Benthic Sampling

To create a data set documenting restoration status, field surveys were conducted for invertebrate and sediment characterization, water column structure, and video imagery. In order to effectively characterize newly created oyster habitat, benthic survey stations were selected as 'On-Reef', 'Off Reef' and 'Reference' sites. The sites were chosen based on the location and extent of oyster habitat obtained from the acoustic data. Due to the size of the area, two locations were selected on the reef, two off the reef and two were used as a reference site at entrance of the embayment. The locations were exported from ArcGIS and uploaded into a Garmin78 Map GPS (Figure 3).

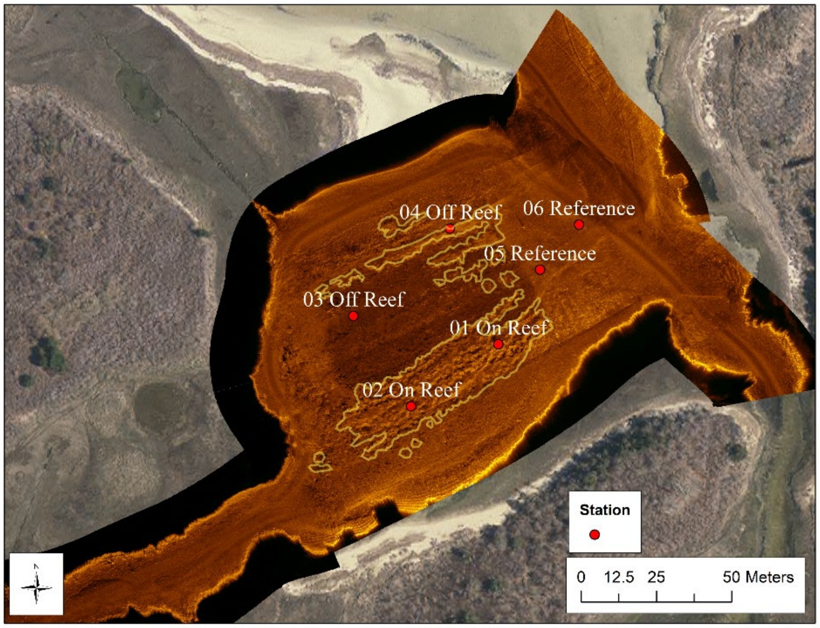

Figure 3. Locations of benthic invertebrate stations on sidescan imagery collected in August 2018 with digitized cultch foot print in yellow.

All samples were collected aboard the R/V Marindin using a Young-Modified Van Veen grab sampler with a surface area of 0.04 m^2 and a depth of 0.1 m below the seafloor, for a total volume of 0.004 m^3 (4 liters). This instrument is well-suited for sand- to mud-sized samples (≤ 4 mm). Water parameters were collected using a YSI (59905-Multimeter) and location was determined with a Garmin78 Map GPS. A GoPro Hero 5™ was attached to the Van Veen grab and high-resolution video was collected for each sample to aid in bottom characterization and documentation (Appendix 01). At each station, three biological replicates were taken with a corresponding waypoint recorded was. All GPS data points were downloaded to a .csv file and imported into ArcGIS for subsequent mapping.

The contents of the Van Veen grab were emptied into a bucket and then sieved through a 1 mm mesh to retain organisms, and substrate greater than 1mm in size. Any large bivalves, crabs, or vertebrates (fish) were measured, counted and identified (or photographed for later identification) before being returned to the water. Larger, mobile organisms collected by this method are considered ancillary data, as benthic grab sample gear cannot provide quantifiable estimates of abundance or density. The material retained on the sieve was preserved in 90% ethanol until processing and analysis.

In addition to the three biological samples taken at each station, a fourth sample was used to document the grain size of the sediment at each station. This sample was taken between the second and third biological replicate to ensure that the sediment sample was generally representative of the substrate sampled by the biological replicates. The surface sediment was transferred to a 100ml Whirl-Pak®, and later dried at the lab for future analysis.

Biological Samples processing

To determine the benthic invertebrates found in each biological grab sample, the contents of each grab were transferred to triple-labeled glass jars and preserved with 90% ethanol with Rose Bengal to dye invertebrates. Date of field sampling, preservation, processing and identification were all recorded on sample tracking data sheets as well as any notes about samples.

To sort out or 'pick' the invertebrates from the substrate, the preservative was drained from the sample and disposed of according to CCS hazardous waste management plan. The sample was spread out into a large white plastic tray and water was added. The sample was visually inspected using a 3-fold magnification on a magnifying LED lamp and all invertebrates were picked out of the sample and sorted into general categories as discerned by the unaided eye (i.e. worms, shellfish, amphipods etc.). All personnel and volunteers were trained by the project biologist on proper picking technique and on general visual cues to find invertebrates. Quality control for each sample was performed by the project biologist by double checking each portion of each sample to ensure that all invertebrates had been found. Specimens were then immediately identified or preserved in 70% ethanol in 20 ml glass scintillation vials.

Specimens were identified by the project biologist using a dissecting microscope. All initial and final identifications, counts, and any notes were recorded on the identification data sheet. Specimens were identified to species level when possible or to genus, families or orders depending on the difficulty of identification. Pictures were taken of representative specimen of each species using a digital microscope camera.

Sediment Samples

To characterize the sediment substrate of the benthic habitat for each sample location, the sediment samples were processed for sediment grain size analysis and organic matter content.

Organic matter content by loss on ignition (LOI): To determine organic matter content of sediments for each sample, 20-30 grams of sediment were placed on pre-weighed aluminum trays, and the wet weight of the sample was recorded before being placed in a drying oven at 105°C for 24 hours. Dried samples were removed from the oven and placed in a desiccator. Each sample was weighed, and the dry weight was recorded. After recording the initial dry weight, all samples were broken up using either a spatula or a mortar and pestle. After the sample was ground, it was re-dried and reweighed to account for any lost material. To determine the proportion of organic matter, the homogenized samples were placed in a muffle furnace at 550°C for four hours. After ignition, the samples were re-weighed, and the percent organic matter as loss on ignition was determined by the following calculation:

$$\text{LOI (\%)} = (M_{dry} - M_{dish}) - (M_{ignite} - M_{dish}) / (M_{dry} - M_{dish}) * 100$$

M_{dry} is the weight of the dried sample (at 105° C) plus the aluminum dish

M_{ignite} is the weight of the ignited sample (at 550° C) plus the aluminum dish

M_{dish} is the weight of the aluminum dish.

Grain size analysis: Percentages of each of the size fractions for each sample were calculated from grain size data measured by the following methods.

Coarse grain size > 64 µm: Sediments samples were split and organic material was burned off in a muffle furnace at 550°C for four hours. Samples were then sieved between 64 µm and 4 mm according to manufactures instructions before processing with a Horbia Camsizer at the University of Massachusetts, Amherst, MA. Processed sediments were retained. All grain size results were saved to .csv files. All data were reported using Wentworth grain size thresholds and classes (Folk, 1974).

Fine grain size < 1 mm: Sediments samples were split and organic material was burned off in a muffle furnace at 550°C for four hours. Sediment were then gently washed with tap water to remove salt and ash. Sediment samples were processed with a Beckman-Coulter laser diffraction particle size analyzer at the University of Massachusetts, Amherst, MA. All grain size results were saved to .csv files. All data were reported using Wentworth grain size thresholds and classes (Folk, 1974).

Benthic habitat mapping framework

Each dataset used in the production of the final data products can be mapped and interpreted separately. However, we know that abiotic factors such as grain size, sediment organic content, and geomorphology explain some amount of the variance observed in benthic community composition. In many cases the reverse may also be true, where certain biotic assemblages may influence the physical composition and/or structure of the environment (e.g., shellfish beds, tube mats, eelgrass beds). These physical-biological relationships are critical to effective resource management, and we therefore attempted to characterize them and extract any information that could be useful for the mapping and management of benthic habitats.

We classified the CMECS Geoform Component and Substrate Component using the physical data followed by classifying benthic community data using the CMECS Biotic Component. Finally, we used statistical approaches to identify physical variables that explained the highest proportion of the variance in the benthic community data, and classified the benthic community data based on these variables. This latter type of classification is referred to as a ‘biotope’ in CMECS, but with the added requirement that the physical-biological associations are predictable and repeated throughout the natural environment. Because the biotopes reported here are based on a single set of observations for each area, we refer to these results as ‘preliminary biotopes’. Preliminary biotopes give us a sense for which physical variables are influencing or driving benthic community composition in each study area.

Physical Characteristics

CMECS Geoforms

The CMECS Geoform component describes the major geomorphic and structural characteristics of the coast and seafloor, but is not intended to be a geological classification per se

(FGDC, 2012). Rather, the Geoform Component describes aspects of the physical environment that are relevant to and drivers of benthic community composition and distribution (FGDC, 2012). We delineated Geoforms by classifying several metrics derived from the bathymetry grid using the Benthic Terrain Modeler (BTM) Toolbox in ArcGIS Desktop (Wright et al., 2012). Using the bathymetry grid as an input, we calculated slope, fine-scale bathymetric position index (BPI), and broad-scale BPI.

We calculated slope for each cell as the maximum rate of change from the cell to its neighbor using the BTM Toolbox. The output was a continuous raster.

BPI is a focal mean calculation where a cell's elevation is compared to surrounding cells within a user-defined area. BPI is greater than zero where ridges or crests exist and less than zero where depressions or valleys exist. BPI is calculated using the following equation,

$$BPI < scalefactor > = int\left(\left(bathy - focalmean(bathy, annulus, irad, orad)\right) + 0.5\right)$$

Where scalefactor = out radius in map units, irad = inner radius of annulus in cells, orad = outer radius of annulus in cells, and bathy = bathymetric grid. We calculated BPI grids for broad-scale and fine-scale features. Broad-scale BPI was calculated using an inner radius = 25 and an outer radius = 250. Fine-scale SPI was calculated using an inner radius = 5 and an outer radius = 25. These search radii therefore could detect features from 5 meters across to 250 meters across. Using the BTM Toolbox, the BPI grids were standardized by subtracting the mean, dividing by the standard deviation, and multiplying by 100.

The classification dictionary used in the BTM Toolbox (Table 1) was developed for this study to distinguish geomorphological features based on Broad- and Fine-scale BPI values, slope, and depth. We used the CMECS Slope Modifier to distinguish between features.

Table 1. Classification dictionary developed in the Benthic Terrain Modeler (BTM). BPI values are standardized and multiplied by 100 (i.e., dimensionless).

Class	Zone	Broad BPI Lower	Broad BPI Upper	Fine BPI Lower	Fine BPI Upper	Slope Lower	Slope Upper	Depth Lower	Depth Upper
1	Basins and channels		-100						
2	Flats > 1m	-100	100		100	0	5	-1	
3	Flats 1 - 3m	-100	100		100	0	5	-3	-1
4	Flats 3 m	-100	100		100	0	5	-3	
5	Bedforms < 5°	-100	100		100	5		-3.5	-3
6	Margins >5°	-100	100		100	5			-3.5
7	Platforms	-100	100	100					
8	Banks	-100							

CMECS Substrate

The CMECS Substrate Component is a characterization of the composition and particle size of the surface layers of the substrate (FGDC, 2012). Substrates represent the non-living components that support, intersperse, or overlay the living components of the seafloor environment (FGDC, 2012). The CMECS Substrate Component uses Wentworth grain size thresholds and classes based on (Folk, 1974).

We used the percentages of gravel, sand, silt, and clay fractions of each sample to classify Substrate Subgroups at each sampling point. Classification was done automatically using SEDCLASS software (Poppe et al., 2003). We then described the relevant Substrate Groups, Subclasses, and Classes for each sample.

To develop a map of substrate types for Shimmo Creek the resulting median grain size surfaces were then classified by CMECS Substrate Subgroups. Importantly, the median grain size metric was expected to yield a different classification result than the classification derived from the station specific weight percentages of gravel, sand, silt, and clay. The resulting median grain size classified according to the Wentworth scale.

Biological Characteristics

CMECS Biotic Component

The CMECS Biotic Component deals with the classification of organisms in both the water column and on the seafloor; here we deal only with organisms on the seafloor (i.e., CMECS Biotic Setting = Benthic Biota). We can further narrow our scope of classification to the Biotic Class 'Faunal bed' since all of the observations were from sediment grab samples. Faunal beds are highly dependent on substrate type and include two Subclasses: 'Attached fauna' and 'Soft sediment fauna'. The next two hierarchical levels are Biotic Groups and Biotic Communities. We defined Biotic Communities based on dominance, then described the appropriate Biotic Group and Class for each Community.

Biotic Communities were defined by cluster analysis of the benthic infauna species data in PRIMER (Clarke and Gorley, 2015). First, the species-sites matrix was reduced to include only those species contributing to the top 95% of the total observed abundance. To verify that this new species-abundance matrix was representative of the benthic community in each area, the correlation coefficient between matrices based on the original and top 95% of total observed abundances were calculated. A Pearson correlation resulted in statistically significant similarity (0.9916) between 100% and 95% abundances. As a result, the 95% abundance matrices were found to be representative of the dataset. Using the top 95% dataset, the mean abundance was calculated for each species across all three replicate samples at each site. Then, the data were fourth root transformed to reduce the influence of highly-abundant species and a dissimilarity matrix was calculated using the Bray-Curtis index of dissimilarity. PRIMER's SIMPORF and Cluster methods were employed, to determine the optimal number of clusters. If the same species was dominant in more than one cluster, they were classified as the same CMECS Biotic Community (FGDC, 2012).

To more fully examine the relationships between physical variables and benthic community composition, distance based lineal modelling (DistLM) was conducted using the PERMANOVA+ extension on PRIMER (PRIMER-E v7, Plymouth). The model analyzes the relationship between a multivariate dataset (benthic community dataset), as described by a resemblance matrix (Bray Curtis dissimilarity) and a set of one or more predictor variables (sediment characteristics) using distance-based redundancy analysis (dbRDA) (Figure 4). The routine allows for sediment characteristics to be considered individually or grouped together in specific sets and obtains p-values testing the null hypothesis (no relationship) using the appropriate permutation methods (Clarke and Warwick, 2001). DistLM does a partition of variation according to a regression or multiple regression model and can be used to analyze models containing a mixture of categorical and continuous variables.

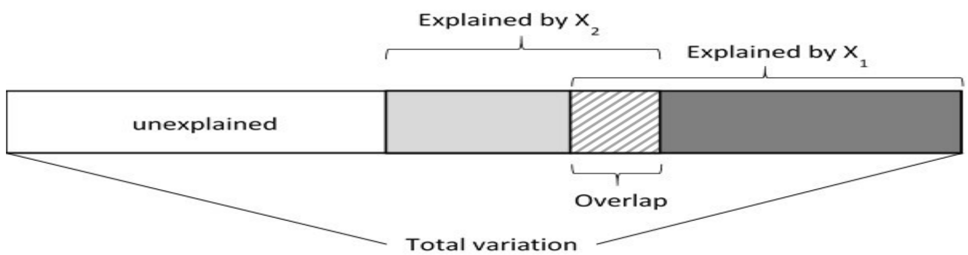

Figure 4. Conceptual diagram of regression as a partitioning of the total variation into portions that are explained by the predictor variables (X_1 and X_2), a portion that can be explained by both variables (overlap) and a portion that is left unexplained. (Clarke and Warwick, 2001).

The predictor variables used for this analysis were 10 sediment characteristics listed in table 2. Grain size metrics were chosen in particular, because they were consistently associated with benthic invertebrate sampling stations. Defining biotopes using only sediment variables allowed for retention of the maximum number of stations examined with DistLM and thus classifying biotopes in the most robust way.

Table 2. Sediment grain size characteristics used to run distance based linear models.

Grain size metric	Grain size metric
% mud	Mode
% sand	Skewness
% gravel	Sorting
% organic content (LOI)	Kurtosis
Mean	Median

Indicator species were determined for the most influential characteristics when possible by using LINKTREE. LINKTREE identifies thresholds in each of the variables (e.g. geoforms or grain size metrics) that correspond to occurrences of different benthic assemblages. The benthic assemblages corresponding to these thresholds were used to determine indicator species for the underlying variables.

An indicator species is defined as frequently associated with certain environmental conditions or characteristics (e.g. Geoform: basins and channels) while being not often associated with any other environmental condition or characteristic (e.g. any other Geoform). Indicator species were calculated according to Dufrene and Legendre (1997):

$$IndVal_{ij} = A_{ij} * B_{ij}$$

Where A_{ij} is the proportion of the individuals of species ‘i' that are present in biotope ‘j’ and B_{ij} is the proportion of stations in biotope ‘j’ that contain species ‘i'.

The indicator species values range from 0 (poor indicator) to 1 (perfect indicator). PRIMER’s RELATE function, based on a Pearson Correlation, was used to determine the significance level of the indicator species. Only indicator species with a significance level < 5% were reported.

Results

Vessel-based Acoustic Surveys

Shimmo Creek was mapped on August 9th 2018. The area mapped has a mean depth of 1.22 m (Figure 5). Acoustic surveys collected a total of 1.32 ha of bathymetric data (Figure 5) and 2.65 ha of sidescan backscatter imagery (Figure 6). The sidescan backscatter settings for the project were set at a 25 m range, yielding a 50 m swath. A 6:1 to 8:1 ratio of water depth to bathymetric coverage was typical for this survey, therefore bathymetric swath widths were directly related to water depths. A total of 1.32 ha of bathymetry was collected at a grid resolution of 1 m (Figure 5). The total coverage was >99% at a grid resolution of 1 m, 97% at 50 cm, and 94% at 25 cm, which is typical for these kinds of datasets. A total of 1677 square meters of oyster habitat was identified within the Sidescan sonar imagery.

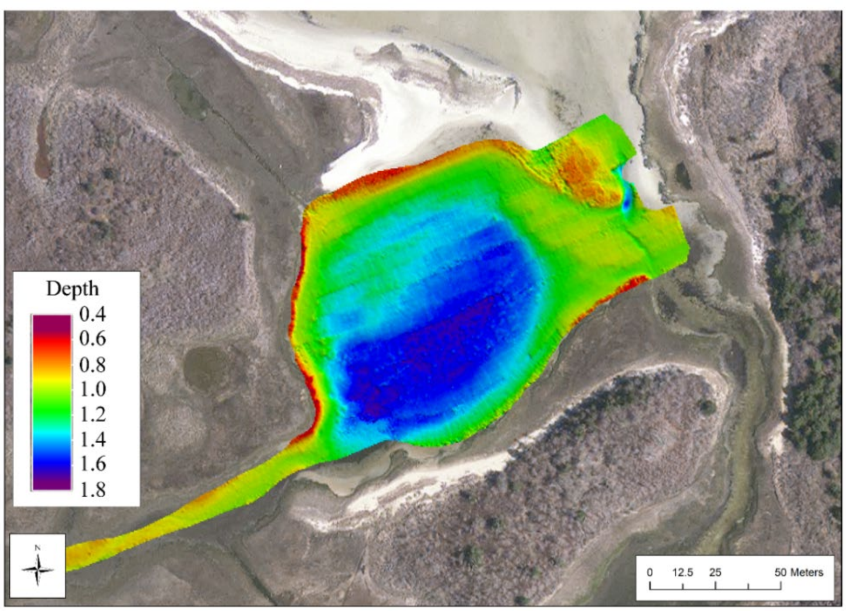

Figure 5. Bathymetric data for Shimmo Creek collected in August 2018 with shallow depths in warmer colors and deeper areas in cooler colors, mean depth over 1.30 ha is 1.22 m.

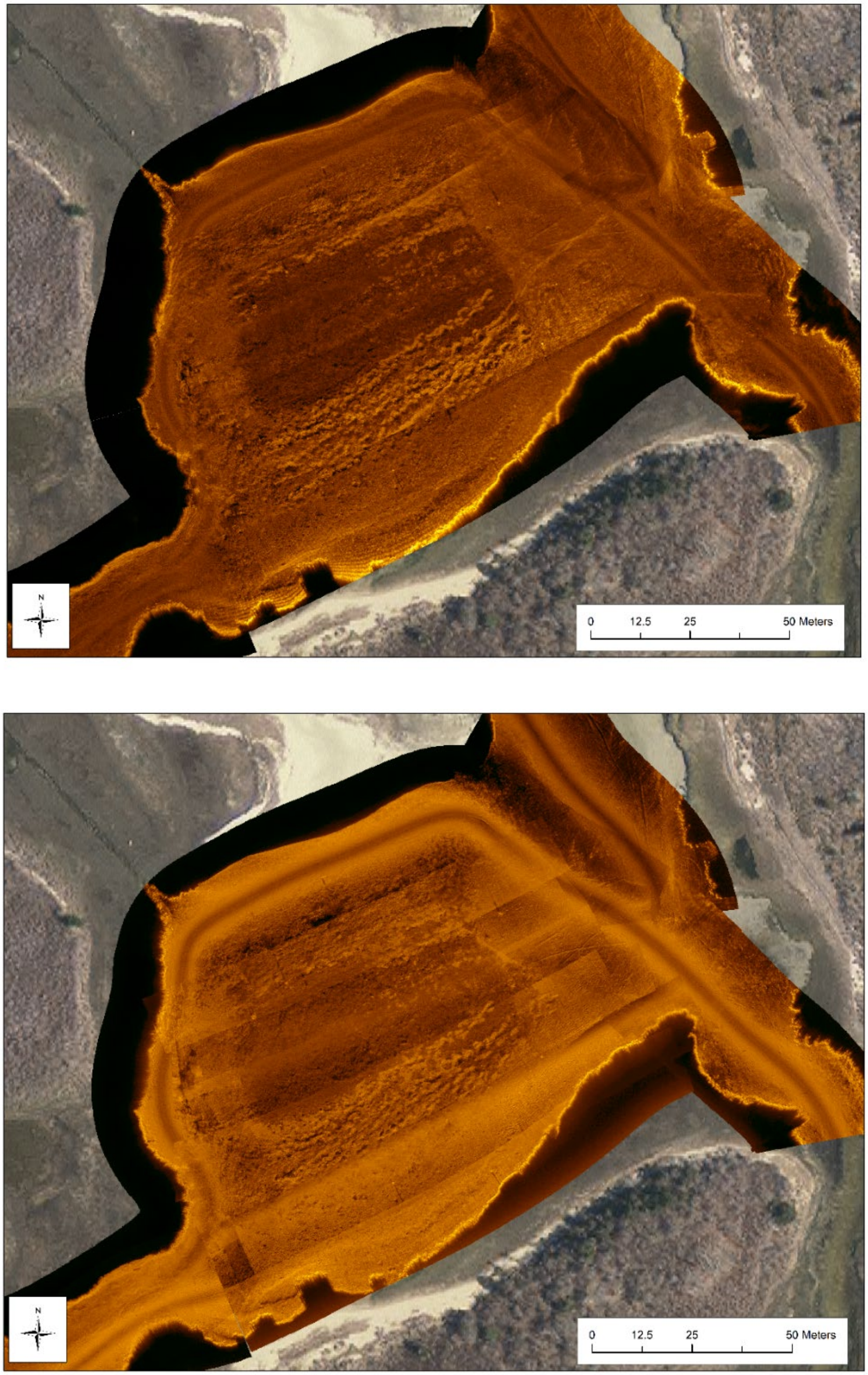

Figure 6. Sidescan sonar imagery from acoustic sonar survey in August 2018. Sidescan imagery collected at 550 kHz on top and 1600 kHz on bottom panel.

In total, 76% of the backscatter imagery was collected with a minimum of 200% overlap and 86% at a 300% overlap (Figure 7). The areas mapped for bathymetry and backscatter imagery are derived from the final surfaces or mosaics, not individual survey lines and/or swaths.

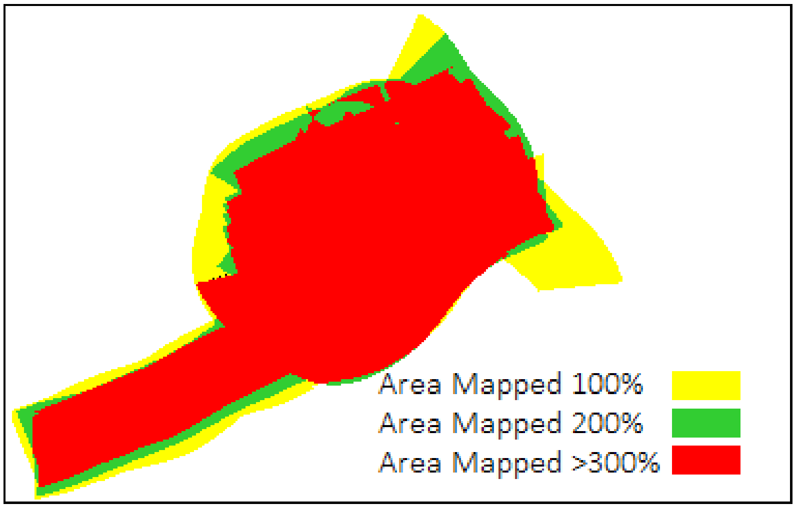

Figure 7. Acoustic survey data coverage of Shimmo Creek collected in August 2018.

Benthic Sampling

On August 10th 2018 Shimmo Creek was examined by performing quadrate sampling of the oyster reefs in order to inform the benthic invertebrate sampling. Approximately 2L of shell were collected within 25x25 cm quadrates across four locations (Figure 8). All shells were examined for oyster larvae and spat and benthic invertebrates were quantified. These data became ancillary data and aided in the benthic grab sampling that was to follow.

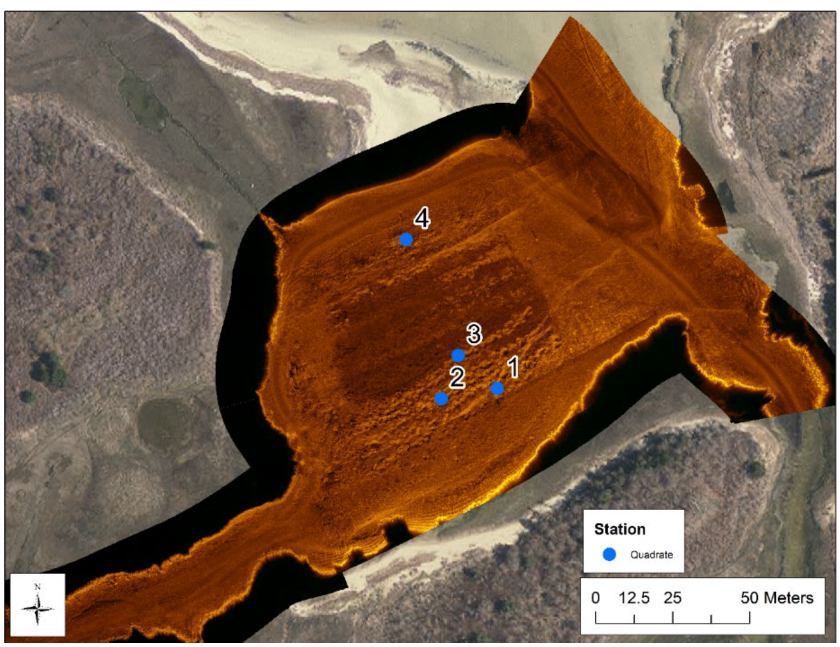

Figure 8. Quadrate locations across Shimmo Creek oyster habitat.

On August 30, 2018, 6 stations within Shimmo Creek were sampled in triplicate, resulting in a total of 18 sieved and preserved biological samples (Figure 3). The locations were determined from the sidescan backscatter imagery of the reef substrate (Figure 9). In addition, sediment samples, water quality parameter data, and video data were collected at each station. Sampling was stratified across 6 stations: 2 'On-Reef'; 2 'Off-Reef'; and 2 'Reference' at the mouth of Shimmo Creek (Figure 3). Video data were collected for examination of surface conditions at the time of sampling (Appendix 1).

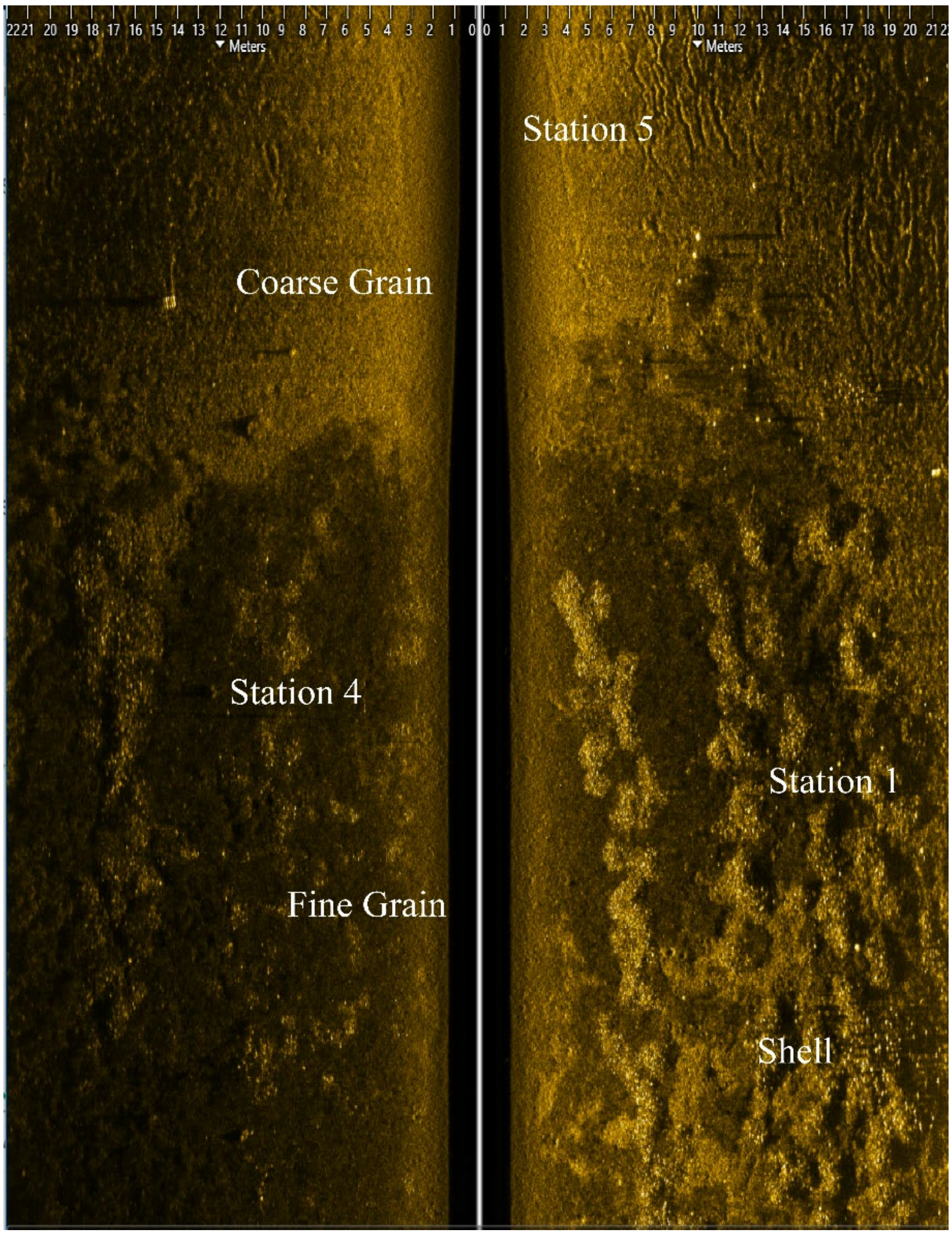

Figure 9. Sidescan water fall (1600 kHz) in at the Shimmo Creek Oyster Habitat Site. Fine Grain Sediment (Bottom Left) is depicted by a dark pixels with 'Off-Reef' station 4. Coarse grain by lighter pixels (Top) with 'Reference' Station 5. Recycled bivalve shell on the right side of the panel along with 'On-Reef' Station 1.

Physical Characteristics

CMECS Geoforms

CMECS Geoforms were created using the Benthic Terrain Modeler extension in ArcGIS10.3 from the bathymetric data collected during the acoustic survey. Slope, broad and fine scale BPI derived from the bathymetric data were utilized to classify the structures throughout Shimmo Creek. Flats and Banks, as defined by CMECS (table 1), were the majority of geoforms found throughout the system (Figure 10). This is not surprising given the low relief of the survey area.

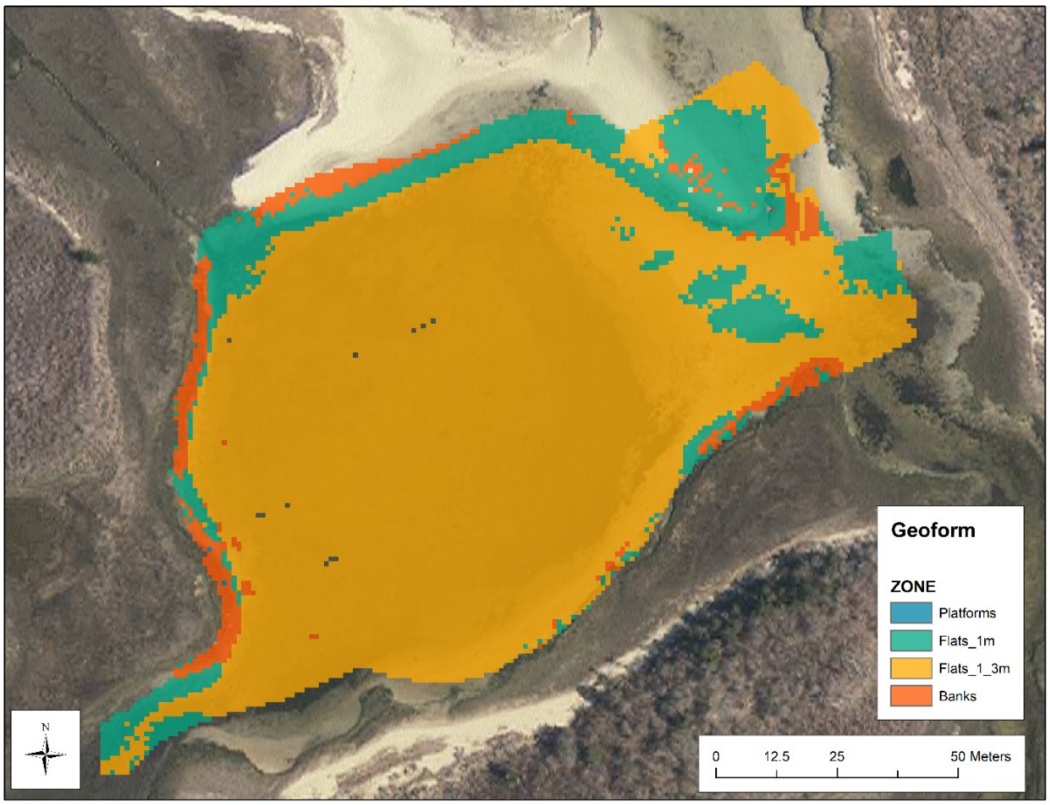

Figure 10. CMECS Geoforms in Shimmo Creek with platforms in blue, flats >1m in green, Flats 1-3m in yellow and banks in orange.

CMECS Substrate

For the CMECS Substrate Group and Subgroup classification median grain size (D_{50}) was used across stations (Figure 11). The results indicate that the majority of sediment throughout the system to be coarse sand (500-1000 µm) at the mouth (reference stations) and progressively finer sediment (~54 µm) as stations move west into the embayment (Figure 11, Table 3).

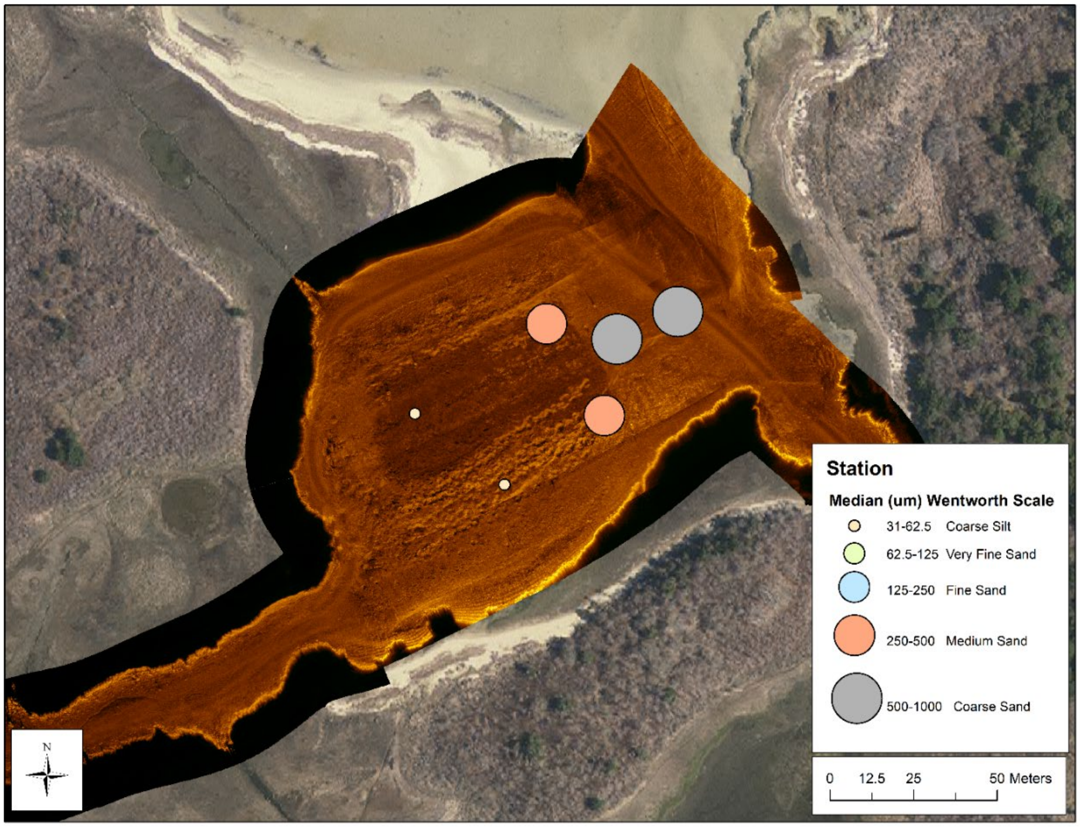

Figure 11. Grain size analysis across benthic invertebrate stations. Wentworth scale indicated by size and color of station.

Table 3. Grain size metrics across stations.

Station	Site	Latitude	Longitude	LOI % organic matter	Median	Gravel (%)	Sand (%)	Mud (%)	Mean	Sorting	Skewness	Kurtosis
NOR_01_242_2018	On Reef	41.28847	-70.067906	4.180	381.4	0.8	82.1	17.1	273.54	3.82	-0.36	0.96
NOR_02_242_2018	On Reef	41.28828	-70.068259	14.737	55.15	0	46.2	53.8	65.23	4.19	0.05	1.12
NOR_03_242_2018	Off Reef	41.28847	-70.068582	18.056	54.23	0	45.1	54.9	68.35	4.41	0.12	1.24
NOR_04_242_2018	Off Reef	41.28872	-70.068116	5.831	144.9	0.5	64.5	35	161.09	5.41	-0.01	0.72
NOR_05_242_2018	Reference	41.28868	-70.067864	0.680	760.8	5.8	94.2	0	788.32	1.71	0.12	1.01
NOR_06_242_2018	Reference	41.28875	-70.067648	0.402	829.2	9.2	90.8	0	859.13	1.80	0.10	0.99

Biological Characteristics

CMECS Biotic Component

Shimmo Creek samples revealed 56 species (Appendix 2) and 17,900 individuals (Appendix 3). PRIMER's SIMPORF and Cluster analysis indicated that the optimal number of clusters is 3 (Figure 12). Classifying each significant cluster into CMECS Biotic Communities based on dominance yielded 2 Biotic Communities (Table 4).

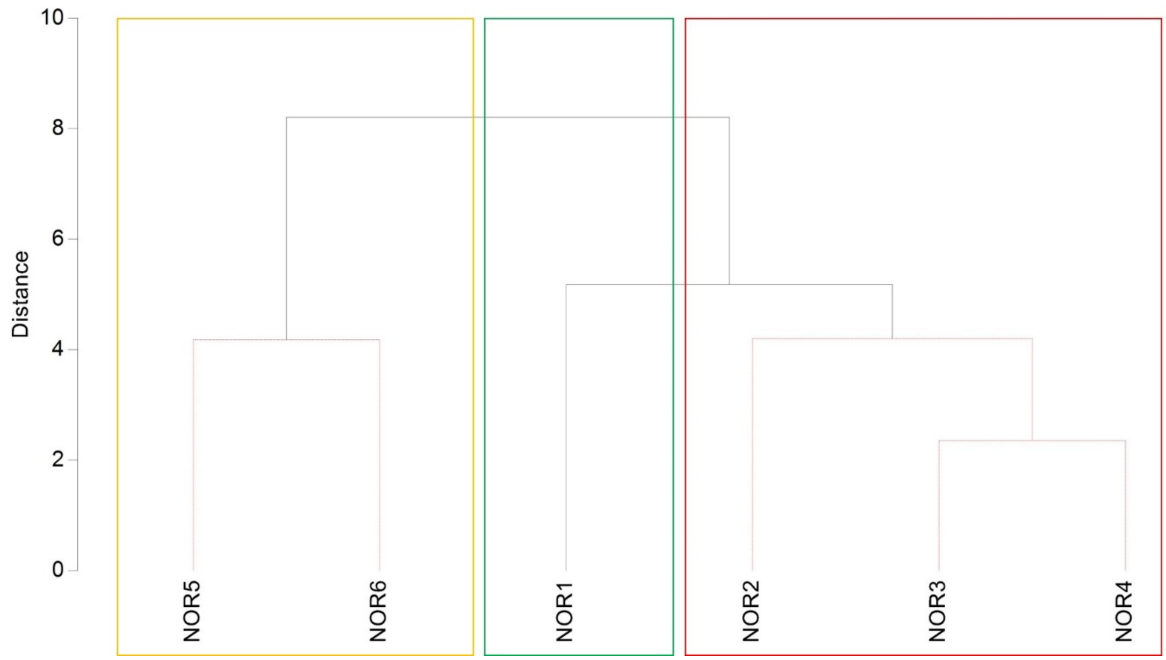

Figure 12. PRIMER's cluster analysis based on species composition at each station. Colored boxes indicate clusters.

Table 4. Calculated Clusters for Shimmo Creek with most abundant species and biotic component classifiaction according to CMECS. Asterisk (*) indicates species not yet included in the official CMECS catalog.

Shimmo cluster	Dominant species	Second most dominant species	CMECS Biotic Community	CMECS Biotic Group	CMECS Biotic Subclass
Cluster 1	*Gemma gemma*	*Hydrobia* sp.	Gemma bed with Hydrobia sp.	Clam Bed with mobile mollusks	Soft sediment fauna
Cluster 2	*Hydrobia sp.**	*Gemma gemma*	Hydrobia bed with *G. gemma*	Mobile mollusks on soft sediment with clams	Soft sediment fauna
Cluster 3	*Hydrobia* sp.*	*Gemma gemma*	Hydrobia bed with *G. gemma*	Mobile mollusks on soft sediment with clams	Soft sediment fauna

Preliminary Biotopes

Categorical biotopes results of PRIMER's DistLM show that a total 87.78% of the species distribution in Shimmo Creek can be explained by sediment characteristics, particularly with %

Gravel (71.46%), Mode (10.25%) and Sorting (6.07%) (Figure 13, Table 5). Mode is the most frequently occurring particle diameter. Sorting describes the distribution or variance of grain size in a sample. Well sorted indicates that sediment grain sizes of a sample are similar (low variance), while poorly sorted points to mixed sediment grain sizes (large variance).

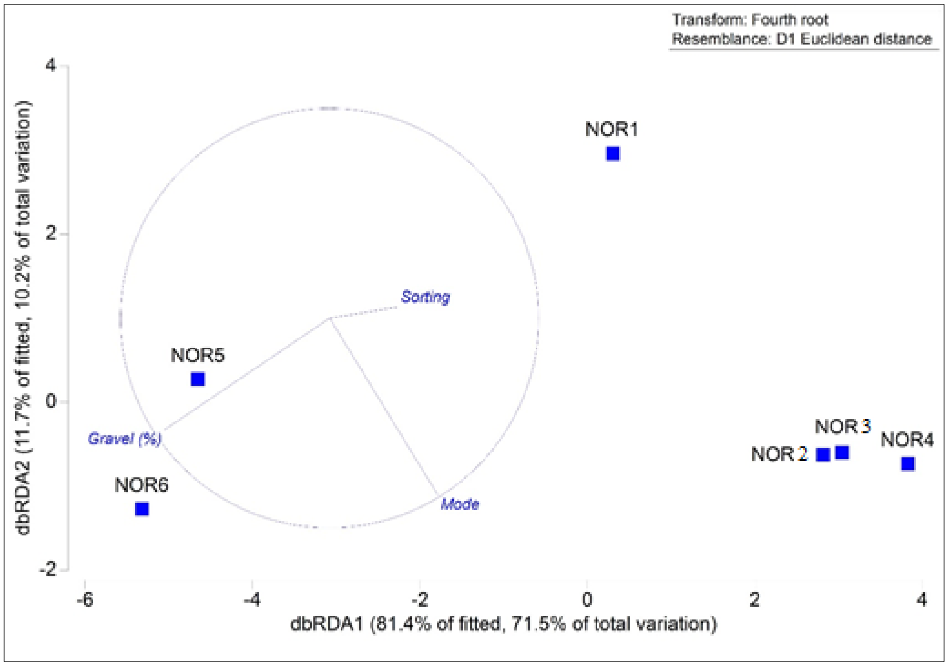

Figure 13. Results of the DistLM analysis using Biotic Communities and grain size metrics in a Non-metric multidimensional scaling plot. Axes are dimensionless, distance of symbols represents their relationship. Symbols correspond to stations 1-6.

LINKTREE showed three splits. The first split was for %gravel at > 5.8% and <0.8%, followed by a split for Mode <0.74 and >4.88 and Sorting >2.14 and <2.07 (Figure 14). The %gravel split separate the stations into some gravel (> 5.8%; biotope 1) and 'almost no gravel' (< 0.8%, biotopes 2 – 4). The remaining biotopes (2 – 4) were split into 'fine' (mode < 0.7; biotope 2) and 'coarse' (mode > 4.8; biotope 3 and 4) with biotope 3 and 4 further split by sorting: very poorly sorted (biotope 3) and poorly sorted (biotope 4). Indicator species were calculated for all biotopes and showed high correlation to their respective biotopes but no significance (Table 5).

Table 5. Characteristics of calculated biotopes and calculated indicator species for each biotope.

Biotope	Characteristics	Species 1	Indicator value	Species 2	Indicator value
1	Gravelly (> 5.8%)	*Gemma gemma*	0.68	*Phylo ornatus*	0.34
2	Less gravelly (< 0.8%) fine (mode: <0.7)	*Hydrobia* sp	0.76	*Phylo ornatus*	0.5
3	Less gravelly (< 0.8%) coarse (>4.8) very poorly sorted	*Gemma gemma*	0.44	*Palaemon pugio*	0.04
4	Less gravelly (< 0.8%) coarse (>4.8) poorly sorted	*Hydrobia* sp	0.49	*Oligochaets*	0.4

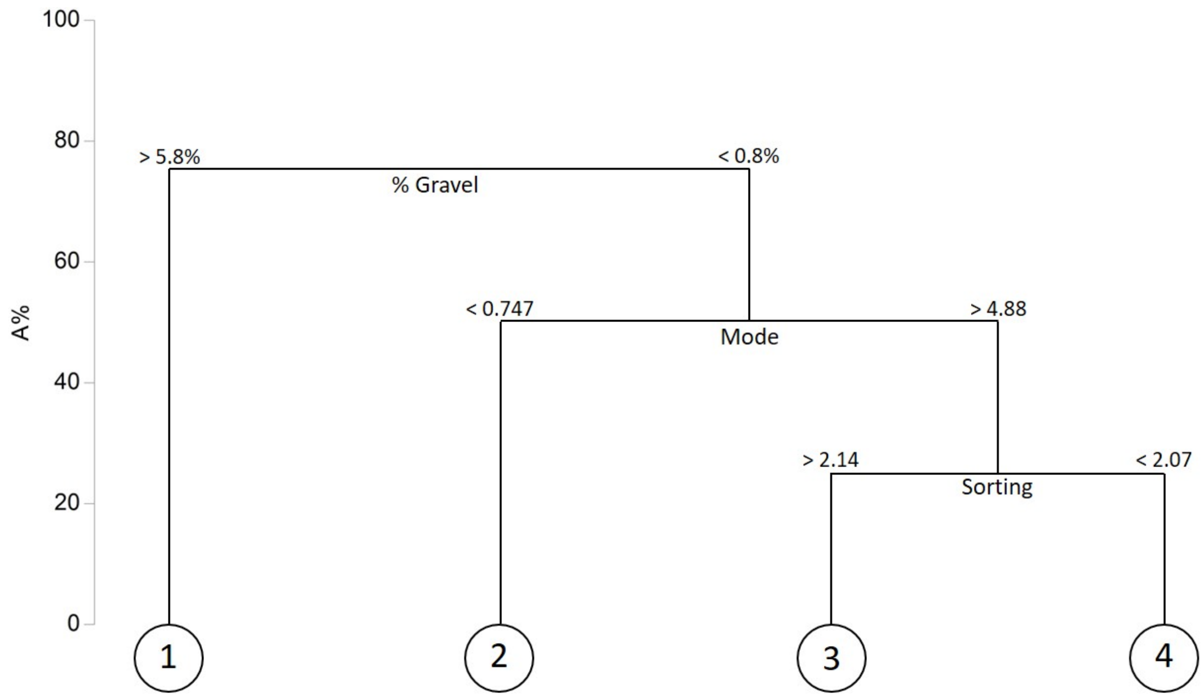

Figure 14. Cluster diagram showing 4 optimal biotopes based PRIMER's distance based linear model and LINKTREE.

Discussion

The ability to measure ecological function in and around an oyster habitat project much depends on the long term monitoring efforts restoration practitioners implement. Here the Center for Coastal Studies established a baseline to be measured against while the oyster habitat project is still young (~ 1 year). The measure of biological diversity 'On-Reef', 'Off-Reef' and away ('Reference') can be tracked throughout time, changing as the habitat matures. The acoustic mapping allows for understanding of reef accretion and expansion. These two metrics are commonly used allowing for comparison to other oyster habitat projects.

Phase-measuring sidescan sonars are well-suited for shallow water mapping, producing high resolution co-located bathymetric and sidescan data. The co-location aided in rapid identification and delineation of the spatial extent of the oyster habitat. Acoustic data collected here allowed for clear distinction between oyster habitat (shell cultch) and surrounding substrates. The swath bathymetry was also used to create the CMECS Geoform component, which in combination with the four other CMECS components, will readily allow this study to be compared to future work.

The acoustic surveys revealed four CMECS Geoforms in Shimmo Creek (Figure 10), but sampling stations were located in only one geoform, (flats between 1 – 3m), due to the homogeneity of physical features. CMECS Substrate components, particularly median grain size, at the stations 'On-Reef' and 'Off-Reef' are a mix of silt and sand. The reference station, at the entrance of the embayment was found to be coarse sand. The shell laid for the reef was covered in a thin layer of silt, re-suspended from the surrounding substrate (Figure 15). The higher siltation and detritus was not found at the reference station meters away, indicating that the siltation of the shell is localized from the surrounding substrates compared to the entrance of the embayment over the coarse sand habitat.

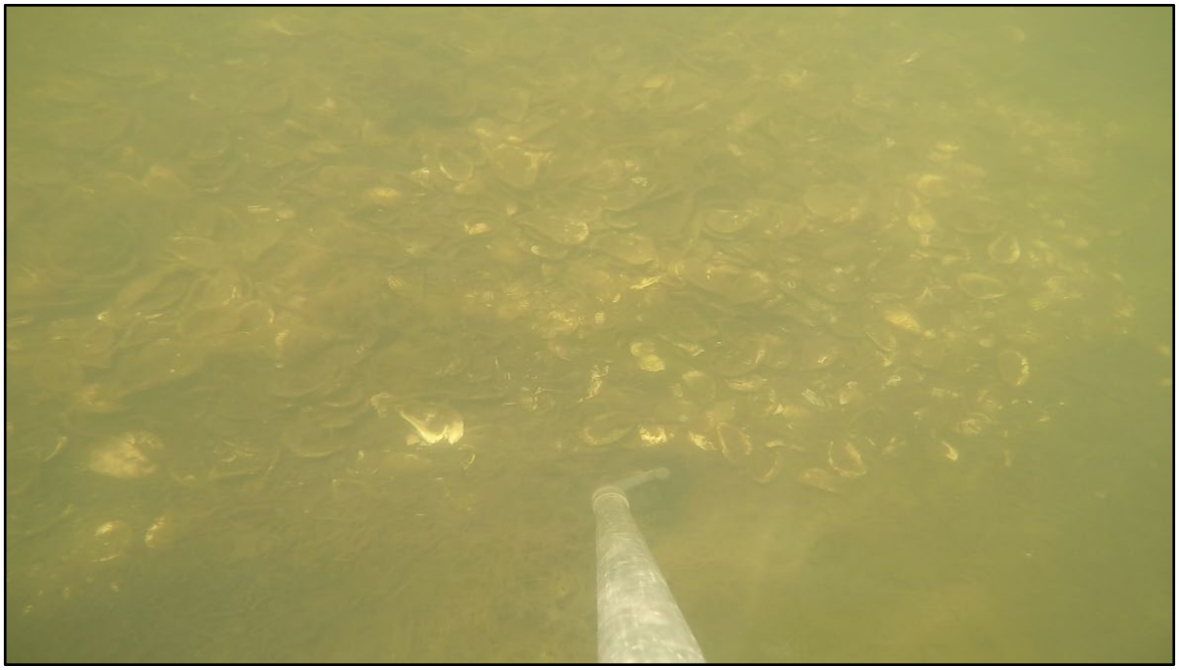

Figure 15. Screen capture from station 01 showing laid cultch (shell) with heavy siltation and detritus (the pole in which camera is attached is in the lower portion of the image).

Sediment variables explained 87.8% of species distribution, indicating that sediment is the key in determining diversity and abundance in Shimmo Creek. Although 'On-Reef' and 'Off Reef' showed communities diverging and had higher species diversity and abundance 'On-Reef' vs 'Off-Reef', sediment characteristics were a bigger driver of community differences.

Two dominant species were identified (*Gemma gemma, Hydrobia sp.*), which were also the most abundant species in the benthic community cluster analysis, suggesting that they play an important role in the overall composition of benthic communities in Shimmo Creek. These two species characterized the CMECS preliminary biotopes (Table 4). Targeted quadrate sampling increased the diversity of 'On-Reef' invertebrate diversity by identifying 11 additional species. This sampling was not random, instead it was laid out near the benthic invertebrate sampling stations and one additional quadrate on the only patch of live oysters found (Station 4 in Figure 8). Since the water column characteristics did not vary significantly between stations and did not improve the statistical model or the description of species distribution, the water column was only characterized (Table A3-5). This further emphasized that the sediment characteristics where the most influential factors in benthic community distribution. The water column data, however, will be essential to compare this current baseline to any future surveys

Data Analysis and Classification Approach

The approaches used for data analysis and classification for this study were chosen based on previous work in similar environments (Borrelli et al. in press, Shumchenia and King 2010) with the broad goal to delineate ecologically meaningful map units rapidly and reproducibly, and create maps using CMECS as a common language. The choice of analysis and classification approach was adapted to what the desired map products were. The raw data collected, analyzed, and classified in this project can be used to address multiple questions and provides a baseline for future ecological monitoring.

Conclusions

This oyster restoration project took place in an area of Shimmo Creek that has several inherent challenges to establishing, self-sustaining, long-term oyster habitat, primarily heavy siltation. The lack of live oysters on any of the shells collected in the benthic invertebrate grabs and on 3 of the 4 quadrate samples indicates that after reef construction in 2018, no successful settlement of oyster larvae has occurred. The only Oysters found were from clutch plantings in 2017 but the reef extent identified was much smaller than the reef that was present from the 2018 cultch planting. Oyster larvae present in the area likely suffer high morality due to being covered by silt and detritus. Benthic invertebrate communities had higher diversity and higher abundance at 'On-Reef' stations compared to the 'Off-Reef' stations, but contained less species and lower abundance when compared to that of the 'Reference' station at the entrance to the embayment ~10s of meters away.

The bathymetry revealed that the laid shell created habitat only 5-10 cm above the surrounding substrate. This low relief reef is not conducive to effective water circulation allowing for a sediment film to persist on the shell, likely smothering any oyster larvae that settle. Due to the silt and detritus present more cultch material is recommended to be planted in mound form, at least 0.5 m above the surrounding substrate. This will aid in the creation of micro-eddies, caused by tidal currents, transporting the sediment off the reef. The addition of spat on shell or transplanting mature oysters onto the reef will benefit the habitat by attracting oyster larvae and moving the silt off the reef by the water filtration action of oysters. This will also create a nearby source of larvae to create future generations of oysters. In communication with the town, it is to be noted spat on cultch was subsequently added in September of 2018 to the reefs surveyed, after the completion of this survey. This study establishes a baseline to compare future monitoring efforts to as this reef ages. The combination of acoustic and invertebrate survey data described here, interpreted within the Coastal and Marine Ecological Classification Standard, will allow for long-term monitoring that is rigorous, repeatable and scientifically defensible.

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Appendix 1 Screen capture from benthic invertebrate stations across the Shimmo Creek study area.

Figure A1-1. Benthic invertebrate sampling station 01. On-reef Sight was found with heavy siltation. Camera 1 m above surface.

Figure A1-2. Benthic invertebrate sampling station 02. On-reef Sight was found with heavy siltation, abundant macro algae. Approximately 0.5 l of shell recovered in the grab sample. Camera 1 m above surface.

Figure A1-3. Benthic invertebrate sampling station 03. Off-Reef site was high turbidity and filamentous algae and woody debris. Camera 1 m above surface.

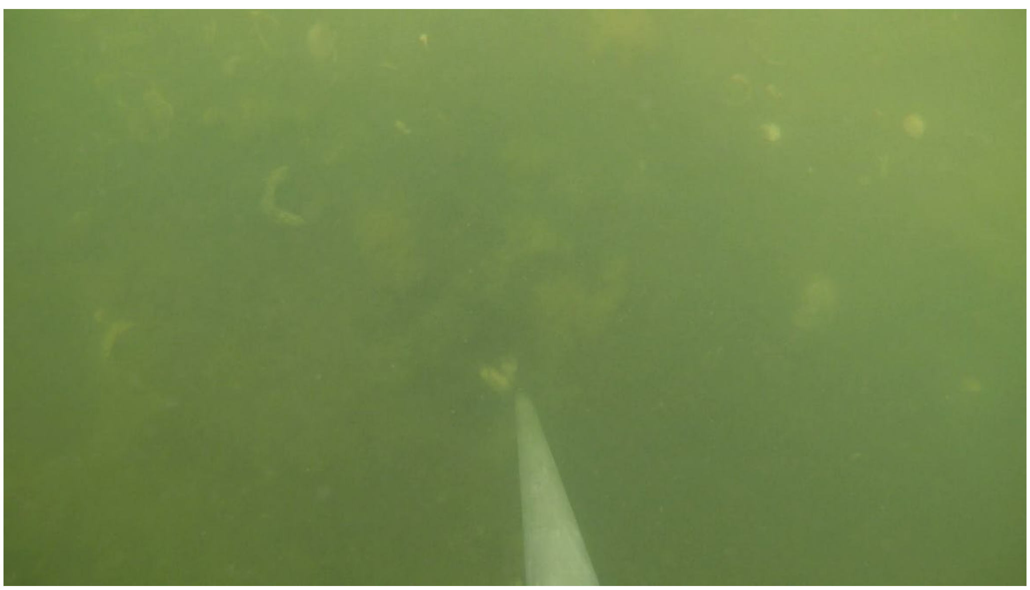

Figure A1-4. Benthic invertebrate sampling station 04. Off-Reef site was high turbidity and filamentous algae and sparse shell. Camera 1 m above surface.

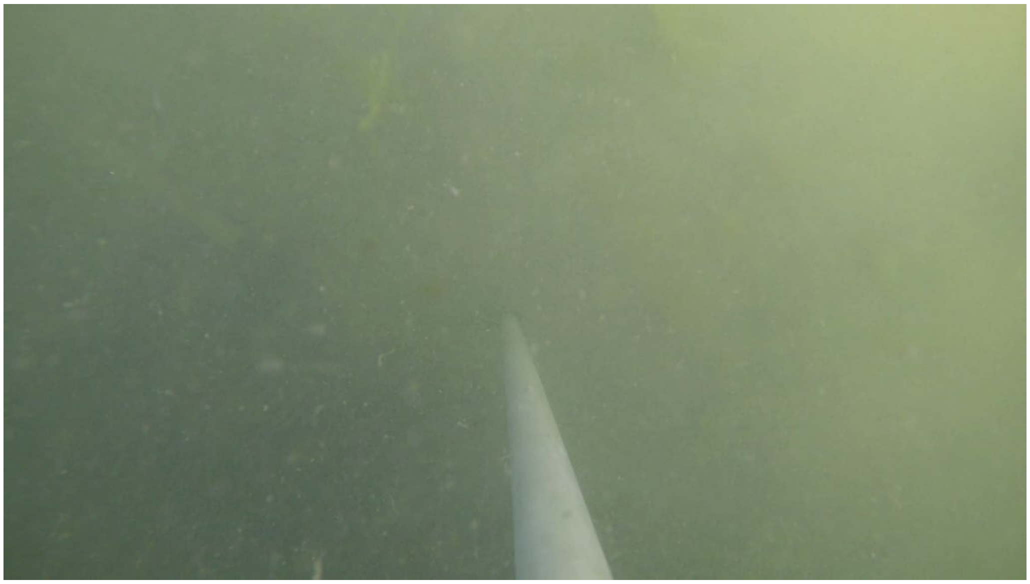

Figure A1-5. Benthic invertebrate sampling station 05. Reference site was high turbidity and filamentous algae and sandy habitat. Camera 1 m above surface.

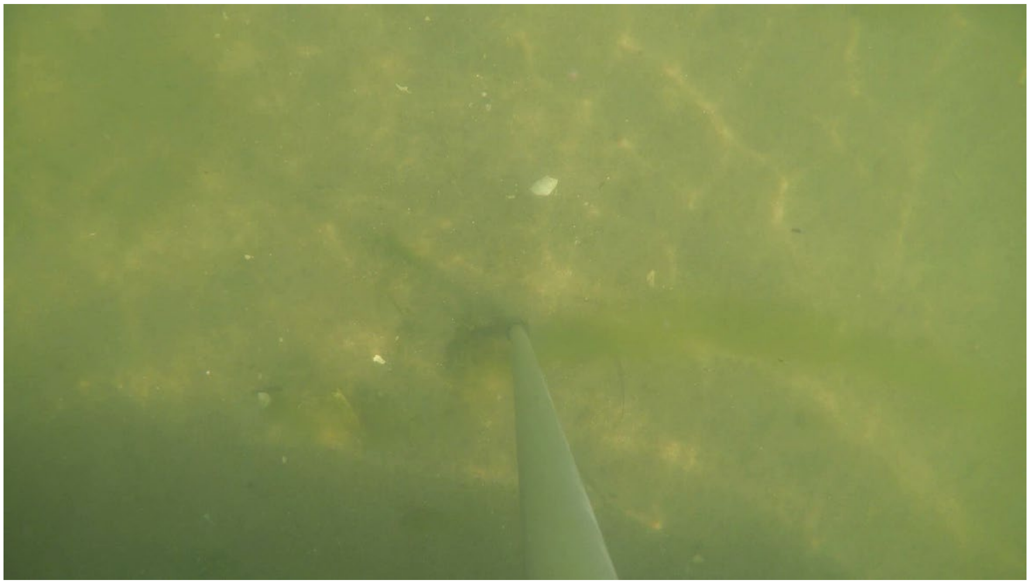

Figure A1-6. Benthic invertebrate sampling station 06. Reference site was low turbidity and filamentous algae and sandy habitat. Camera 1 m above surface.

Appendix 2 List of species present in Shimmo Creek

Table A2-1 List of species present in Shimmo Creek

Species	Genus	Family	Order	Class	Phylum
Ameritella agilis	Ameritella	Tellinidae	Cardiida	Bivalvia	Mollusca
Ampelisca macrocephala	Ampelisca	Ampeliscidae	Amphipoda	Malacostraca	Arthropoda
Amphitrite ornata	Amphitrite	Terebellidae	Terebellida	Polychaeta	Annelida
Ampithoe longimana	Ampithoe	Ampithoidae	Amphipoda	Malacostraca	Arthropoda
Arabella iricolor	Arabella	Oenonidae	Eunicida	Polychaeta	Annelida
Astyris lunata	Astyris	Columbellidae	Neogastropoda	Gastropoda	Mollusca
Chiridotea coeca	Chiridotea	Chaetiliidae	Isopoda	Malacostraca	Arthropoda
Crangon septemspinosa	Crangon	Crangonidae	Decapoda	Malacostraca	Arthropoda
Crepidula fornicata	Crepidula	Calyptraeidae	Littorinimorpha	Gastropoda	Mollusca
Drilonereis longa	Drilonereis	Oenonidae	Eunicida	Polychaeta	Annelida
Elasmopus levis	Elasmopus	Maeridae	Amphipoda	Malacostraca	Arthropoda
Gemma gemma	Gemma	Veneridae	Venerida	Bivalvia	Mollusca
Goniada maculata	Goniada	Goniadidae	Phyllodocida	Polychaeta	Annelida
Leptosynapta tenuis	Leptosynapta	Synaptidae	Apodida	Holothuroidae	Echinodermata
Lysianopsis alba	Lysianopsis	Lysianassidae	Amphipoda	Malacostraca	Arthropoda
Melita nitida	Melita	Melitidae	Amphipoda	Malacostraca	Arthropoda
Mercenaria mercenaria	Mercenaria	Veneridae	Venerida	Bivalvia	Mollusca
Microdeutopus gryllotalpa	Microdeutopus	Aoridae	Amphipoda	Malacostraca	Arthropoda
Mya arenaria	Mya	Myidae	Myida	Bivalvia	Mollusca
Palaemon pugio	Palaemon	Palaemonidae	Decapoda	Malacostraca	Arthropoda
Palaemon vulgaris	Palaemon	Palaemonidae	Decapoda	Malacostraca	Arthropoda
Parougia caeca	Parougia	Dorvilleidae	Eunicida	Polychaeta	Annelida
Phylo ornatus	Phylo	Orbiniidae		Polychaeta	Annelida
Sesarma reticulatum	Sesarma	Sesarmidae	Decapoda	Malacostraca	Arthropoda
Sphaeroma quadridentatum	Sphaeroma	Sphaeromatidae	Isopoda	Malacostraca	Arthropoda
Testudinalia testudinalis	Testudinalia	Lottiidae		Gastropoda	Mollusca
Amphitoe sp	Ampithoe	Ampithoidae	Amphipoda	Malacostraca	Arthropoda
Apocorophium acutum	Apocorophium	Corophiidae	Amphipoda	Malacostraca	Arthropoda
Balanidae		Balanidae	Sessilia	Hexanauplia	Arthropoda
Capitella sp	Capitella	Capitellidae		Polychaeta	Annelida

Species	Genus	Family	Order	Class	Phylum
Crassostrea virginica	Crassostrea	Ostreidae	Ostreida	Bivalvia	Mollusca
Cumacea			Cumacea	Malacostraca	Arthropoda
Eteone longa	Eteone	Phyllodocidae	Phyllodocida	Polychaeta	Annelida
Eumida sanguinea	Eumida	Phyllodocidae	Phyllodocida	Polychaeta	Annelida
Gammarus sp	Gammarus	Paratanaidae	Tanaidacea	Malacostraca	Arthropoda
Glycera americana	Glycera	Glyceridae	Phyllodocida	Polychaeta	Annelida
Hediste diversicolor	Hediste	Nereididae	Phyllodocida	Polychaeta	Annelida
Hydrobia sp	Hydrobia	Hydrobiidae	Littorinimorpha	Gastropoda	Mollusca
Neanthes acuminata	Neanthes	Nereididae	Phyllodocida	Polychaeta	Annelida
Oligochaeta				Clitellata	Annelida
Pagurus arcuatus	Pagurus	Paguridae	Decapoda	Malacostraca	Arthropoda
Phascolion strombus	Phascolion	Phascolionidae	Golfingiida	Sipunculidae	Sipuncula
Polydora sp	Polydora	Spionidae	Spionida	Polychaeta	Annelida
Polyoidae		Polynoidae	Phyllodocida	Polychaeta	Annelida
Porifera					Porifera
Prionospio steenstrupi	Prionospio	Spionidae	Spionida	Polychaeta	Annelida
Pygospio elegans	Pygospio	Spionidae	Spionida	Polychaeta	Annelida
Salvatoria clavata	Salvatoria	Syllidae	Phyllodocida	Polychaeta	Annelida
Syllidae sp		Syllidae	Phyllodocida	Polychaeta	Annelida
Tagelus sp	Tagelus	Solecurtidae	Cardiida	Bivalvia	Mollusca
Tanaidacea			Tanaidacea	Malacostraca	Arthropoda
Turbonilla	Turbonilla	Pyramidellidae		Gastropoda	Mollusca
UN ID Bivalve				Bivalvia	Mollusca
UN ID Amphipod			Amphipoda	Malacostraca	Arthropoda
Xanthidae		Xanthidae	Decapoda	Malacostraca	Arthropoda

Appendix 3 Raw data collected for Shimmo Creek across stations.

Table A3-1 Species distribution at stations 1 – 6 in Shimmo Creek with total counts of each species on the right and total counts of individuals at each station on the bottom. Data from quadrate sampling is also present.

Species	NOR1	NOR2	NOR3	NOR4	NOR5	NOR6	NOR Q	Total
Ameritella agilis	0	0	0	0	2	1	0	**3**
Ampelisca macrocephala	1	0	0	0	0	0	0	**1**
Amphitoe sp	0	0	1	0	0	0	0	**1**
Amphitrite ornata	1	0	0	0	6	0	0	**7**
Ampithoe longimana	0	0	0	0	1	0	1	**2**
Apocorophium acutum	1	0	0	0	0	0	2	**3**
Arabella iricolor	5	3	0	0	12	58	0	**78**
Astyris lunata	0	0	0	0	0	0	1	**1**
Balanidae	0	0	1	0	0	0	0	**1**
Capitella sp	12	0	1	1	12	6	1	**33**
Chiridotea coeca	1	0	0	0	32	107	0	**140**
Crangon septemspinosa	0	0	0	1	0	0	0	**1**
Crassostrea virginica	0	0	0	0	0	0	9	**9**
Crepidula fornicata	0	1	0	0	1	2	0	**4**
Cumacea	1	0	0	0	3	3	0	**7**
Drilonereis longa	0	0	0	0	2	0	7	**9**
Elasmopus levis	1	0	0	0	0	0	0	**1**
Eteone longa	2	0	0	0	1	2	0	**5**
Eumida sanguinea	0	0	0	0	0	0	1	**1**
Gammarus sp	0	0	6	0	0	2	1	**9**
Gemma gemma	418	13	2	22	2868	4802	1	**8126**
Glycera americana	6	0	0	0	0	0	0	**6**
Goniada maculata	0	0	0	0	0	8	0	**8**
Hediste diversicolor	8	5	0	0	65	81	6	**165**
Hydrobia sp	96	208	4	1	4823	3143	2	**8277**
Leptosynapta tenuis	0	0	0	0	1	1	0	**2**
Lysianopsis alba	0	1	1	0	0	2	1	**5**
Melita nitida	0	1	0	0	0	0	0	**1**
Mercenaria mercenaria	0	0	0	0	0	0	1	**1**
Microdeutopus gryllotalpa	3	9	1	1	5	0	3	**22**
Mya arenaria	0	0	0	0	1	1	0	**2**
Neanthes acuminata	8	0	0	0	0	0	0	**8**
Oligochaeta	4	1	0	1	188	100	475	**769**
Pagurus arcuatus	0	0	0	0	0	1	0	**1**
Palaemon pugio	0	0	5	5	0	0	0	**10**
Palaemon vulgaris	0	0	0	0	0	0	5	**5**
Parougia caeca	0	0	0	0	0	16	0	**16**
Phascolion strombus	0	0	0	0	0	1	1	**2**

Species	NOR1	NOR2	NOR3	NOR4	NOR5	NOR6	NOR Q	Total
Phylo ornatus	37	26	0	0	8	2	1	**74**
Polydora sp	0	1	0	0	0	0	1	**2**
Polyoidae	2	0	0	0	4	0	1	**7**
Prionospio steenstrupi	5	0	1	0	3	11	1	**21**
Pygospio elegans	1	1	0	0	0	3	0	**5**
Salvatoria clavata	0	0	0	0	3	2	0	**5**
Sesarma reticulatum	0	1	0	0	0	0	0	**1**
Sphaeroma quadridentatum	0	0	0	0	2	4	0	**6**
Porifera	0	0	0	0	0	0	1	**1**
Syllidae sp	0	2	0	0	0	0	0	**2**
Tagelus sp	1	0	0	0	0	0	0	**1**
Tanaidacea	0	0	0	0	1	1	0	**2**
Testudinalia testudinalis	4	0	0	0	0	0	7	**11**
Turbonilla	0	0	0	0	0	1	0	**1**
un ID Amphipod	0	0	0	0	0	2	4	**6**
un ID Bivalve	0	0	0	0	0	1	0	**1**
Xanthidae	0	0	0	0	0	0	11	**11**
Total	**619**	**273**	**23**	**32**	**8044**	**8364**	**545**	**17900**

Table A3-2. CMECS Biotic Component classifications for Shimmo Creek Stations 1-6 and quadrats. Asterisk (*) indicate species not yet part of the CMECS catalog.

Station	Component	Biotic Setting	Biotic Class	Biotic Subclass	Biotic group	Biotic Community	Most abundant species
NOR01	Biotic	Benthic/Attached Biota	Faunal Bed	Soft sediment fauna	Clam bed	Gemma bed	*Gemma gemma*
NOR02	Biotic	Benthic/Attached Biota	Faunal Bed	Soft sediment fauna	Mobile mollusks on soft sediment	Hydrobia bed	*Hydrobia sp.**
NOR03	Biotic	Benthic/Attached Biota	Faunal Bed	Soft sediment fauna	Clam bed	Gemma bed	*Gemma gemma*
NOR04	Biotic	Benthic/Attached Biota	Faunal Bed	Soft sediment fauna	Clam bed	Gemma bed	*Gemma gemma*
NOR05	Biotic	Benthic/Attached Biota	Faunal Bed	Soft sediment fauna	Mobile mollusks on soft sediment	Hydrobia bed	*Hydrobia sp.**
NOR06	Biotic	Benthic/Attached Biota	Faunal Bed	Soft sediment fauna	Mobile mollusks on soft sediment	Hydrobia bed	*Hydrobia sp.**
NOR Q	Biotic	Benthic/Attached Biota	Faunal Bed	Soft sediment fauna	small surface-burrowing fauna	Oligochaet bed	Oligochaets

Table A3-3. CMECS Substrate Component classifications for Shimmo Creek Stations 1-6.

Station	Component	Substrate Origin	Substrate Class	Substrate Subclass	Substrate Group
NOR01	Substrate	Geologic Substrate	Unconsolidated mineral substrate	fine unconsolidated substrate	Slightly Gravelly Muddy Sand
NOR02	Substrate	Geologic Substrate	Unconsolidated mineral substrate	coarse unconsolidated substrate	Sandy Mud
NOR03	Substrate	Geologic Substrate	Unconsolidated mineral substrate	fine unconsolidated substrate	Slightly Gravelly Muddy Sand
NOR04	Substrate	Geologic Substrate	Unconsolidated mineral substrate	fine unconsolidated substrate	Slightly Gravelly Muddy Sand
NOR05	Substrate	Geologic Substrate	Unconsolidated mineral substrate	coarse unconsolidated substrate	Gravelly Sand
NOR06	Substrate	Geologic Substrate	Unconsolidated mineral substrate	coarse unconsolidated substrate	Gravelly Sand

Table A3-4. CMECS Geoform Component classifications for Shimmo Creek Stations 1-6.

Station	Tectonic Setting Subcomponent	Physiographic Setting Subcomponent	Geoform Level 1	Geoform Level 2
NOR01	Passive Continental Margin	Lagoonal Estuary	Barrier Flat	1-3 m deep
NOR 02	Passive Continental Margin	Lagoonal Estuary	Barrier Flat	1-3 m deep
NOR03	Passive Continental Margin	Lagoonal Estuary	Barrier Flat	less than 1 m deep
NOR04	Passive Continental Margin	Lagoonal Estuary	Barrier Flat	less than 1 m deep
NOR05	Passive Continental Margin	Lagoonal Estuary	Barrier Flat	1-3 m deep
NOR06	Passive Continental Margin	Lagoonal Estuary	Barrier Flat	1-3 m deep

Table A3-5. Water quality parameters collected on August 30th 2018.

Station	Latitude	Longitude	DO_mg/L	pH	Temperature C	Salinity ppt
NOR_01_242_2018	41.28847	-70.067906	9.99	8.18	28.30	31.70
NOR_02_242_2018	41.28828	-70.068259	9.20	8.49	28.70	31.80
NOR_03_242_2018	41.28847	-70.068582	10.02	8.72	28.50	31.79
NOR_04_242_2018	41.28872	-70.068116	11.23	8.76	28.57	31.81
NOR_05_242_2018	41.28868	-70.067864	11.46	8.77	28.60	31.73
NOR_06_242_2018	41.28875	-70.067648	12.01	8.83	28.10	31.60

Appendix 4 Images of benthic invertebrates under microscope.

Figure A4-1. *Arabella iricolor* found at Station 01 sample 01.

Figure A4-2. *Hediste diversicolor* found at Station 01 sample 01.

Figure A4-3. *Neanthes acuminata* found at Station 01 sample 01.

Figure A4-4. *Pygospio elegans* found at Station 01 sample 01.

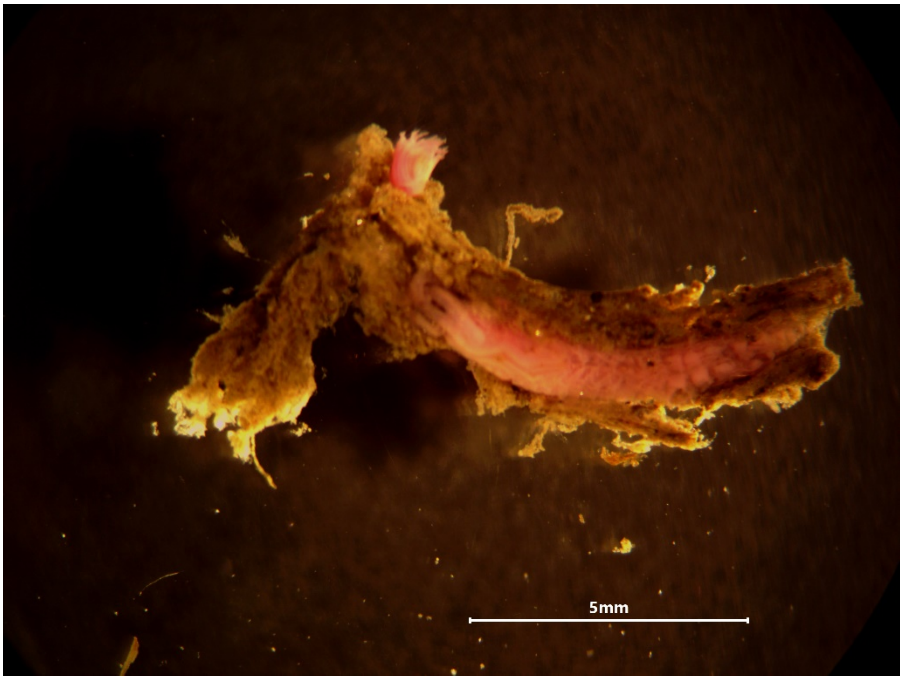

Figure A4-5. *Pygospio elegans* found at Station 02 sample 01.

Figure A4-6. *Sesarma reticulatum* found at Station 02 sample 01.

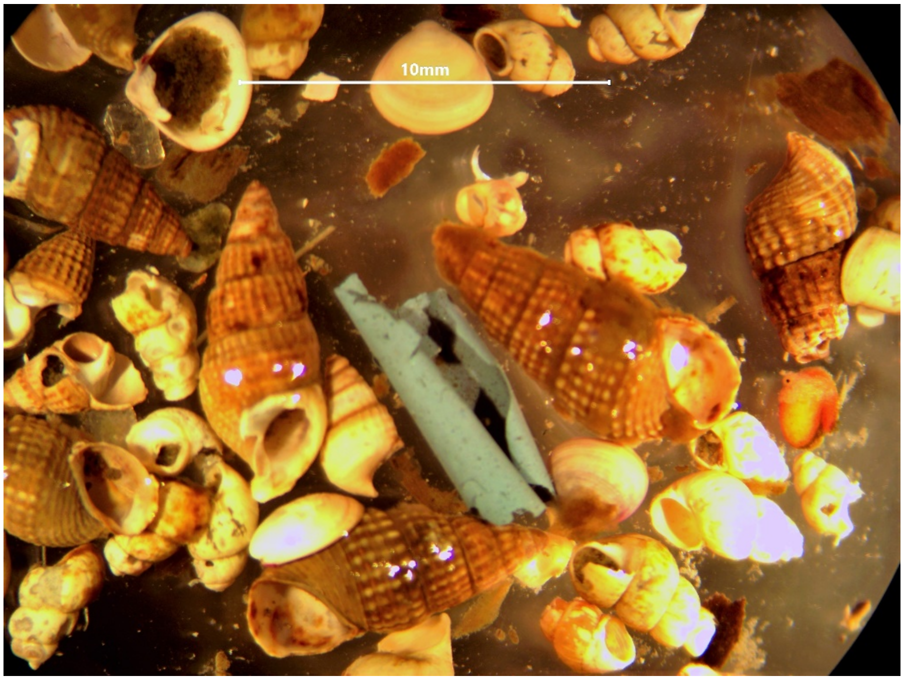

Figure A4-7. Plastic found at Station 04 sample 01.

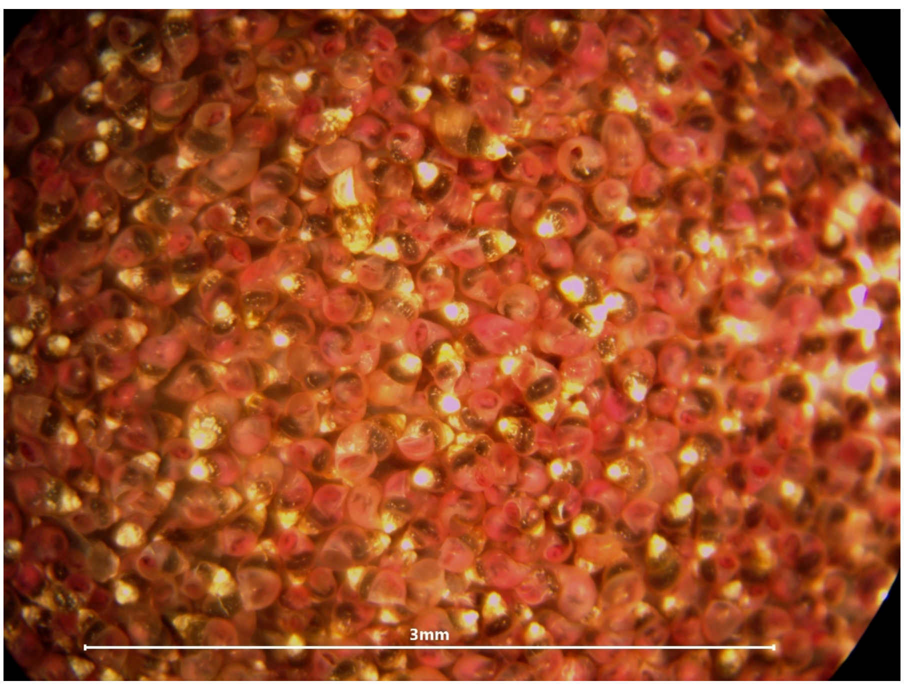

Figure A4-8. *Hydrobia spp.* found at Station 06 sample 01.

Figure A4-9. *Tanaid* found at Station 06 sample 02.

Figure A4-10. *Corophium acutem* found at quadrate 04.

Figure A4-11. *Polydora spp* found at quadrate 04.

Figure A4-12. *Lysianopsis alba* found at Station 02 sample 03.

Figure A4-13. *Microdeutopus gryllotalpa* found at Station 02 sample 3

Figure A4-14 Marine Debris (pen) found at Station 03 sample 02.

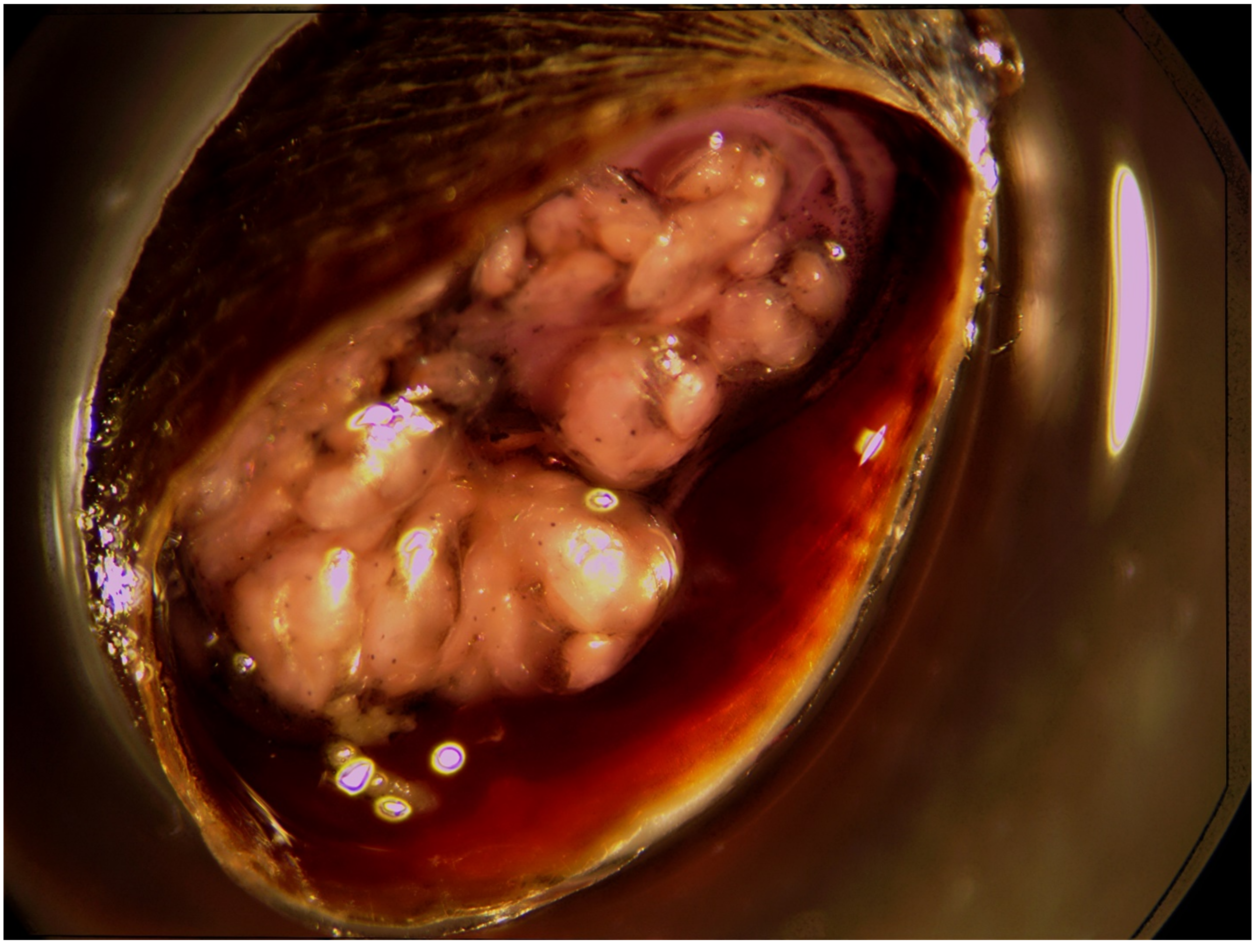

Figure A4-15. *Crepidula fornicata* eggs found at Station 06 sample 03.